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Fair I/O Scheduler for Alleviating Read/Write Interference by Forced Unit Access in Flash Memory

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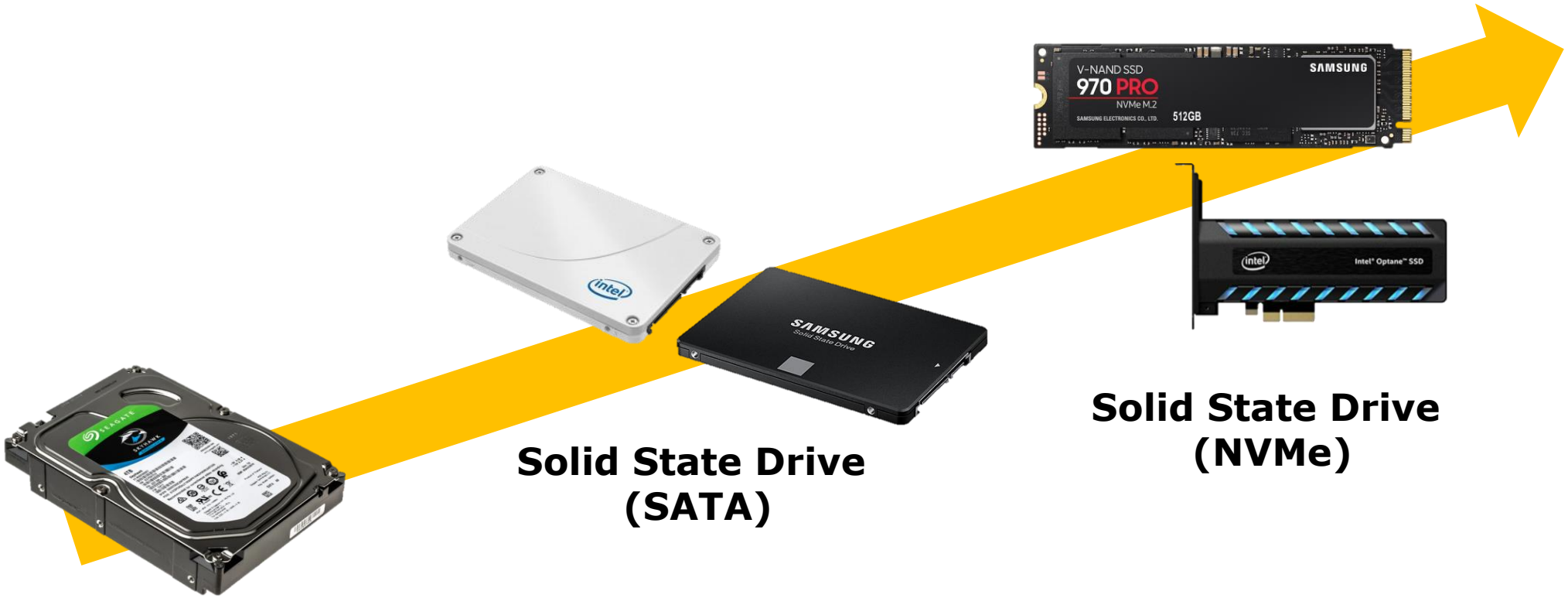
Introduction

Storage Trends



Hard Disk Drive

Solid State Drive (SATA)

Solid State Drive (NVMe)

> 1 *M* IOPS

Sub-msec latency

I/O Interference

Multiple tenants share the same storage device.

Challenge

Alleviating I/O Interference among the multiple tenants.

FUA Interference

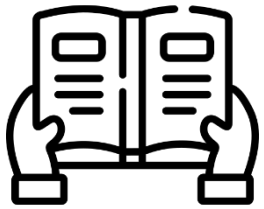
- Forced Unit Access (FUA) is a flag set for the I/O command.
  - FUA enforces the data to directly reflect to the disk.
  - QEMU-KVM directsync cache mode & Microsoft SQL server

- Read/Write interference in flash chip
  - Read is postponed by the preceding write in the same die.
  - Write latency in flash chip: 10-40 times longer than read.

- **FUA Interference**
  - The FUA-flagged write is highly related to the read/write interference
  - The FUA-flagged write requests from host can occur the read/write interference.

Motivation

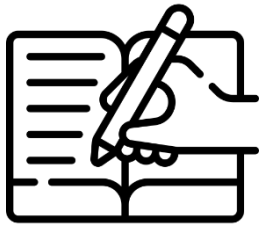
Simulation of FUA Interference



Reader

Random Read

Direct & Sync (`fio`)



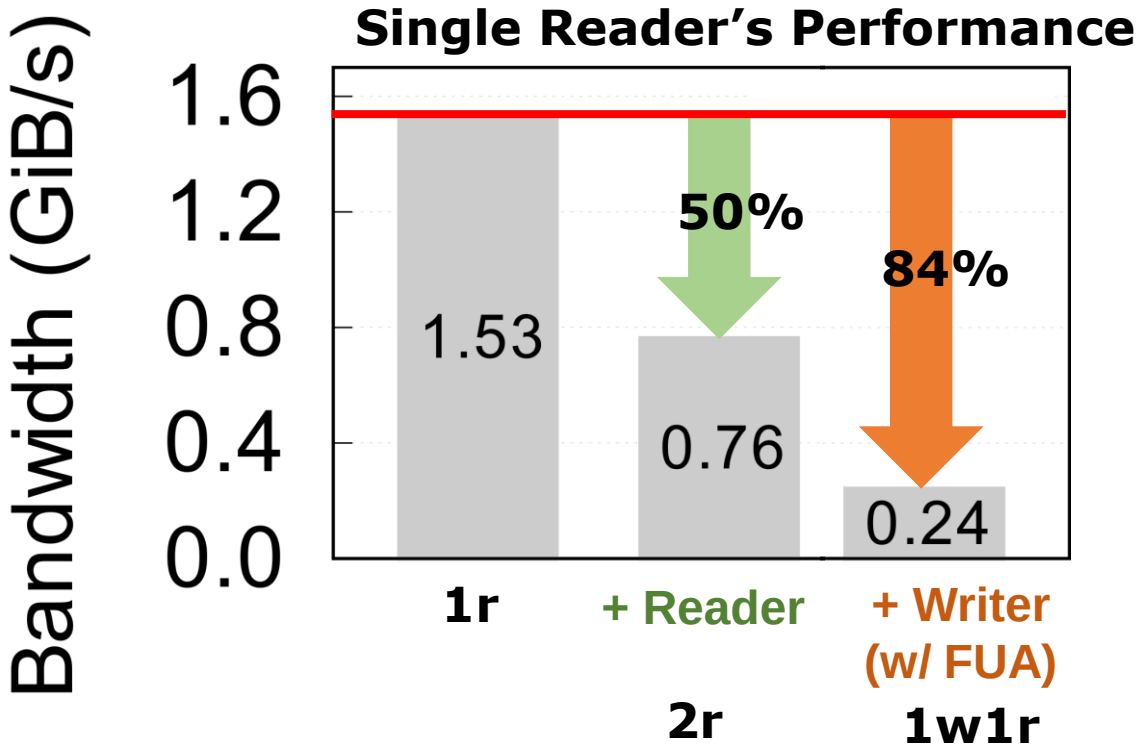
Writer

Random Write

Direct & Sync (`fio`)

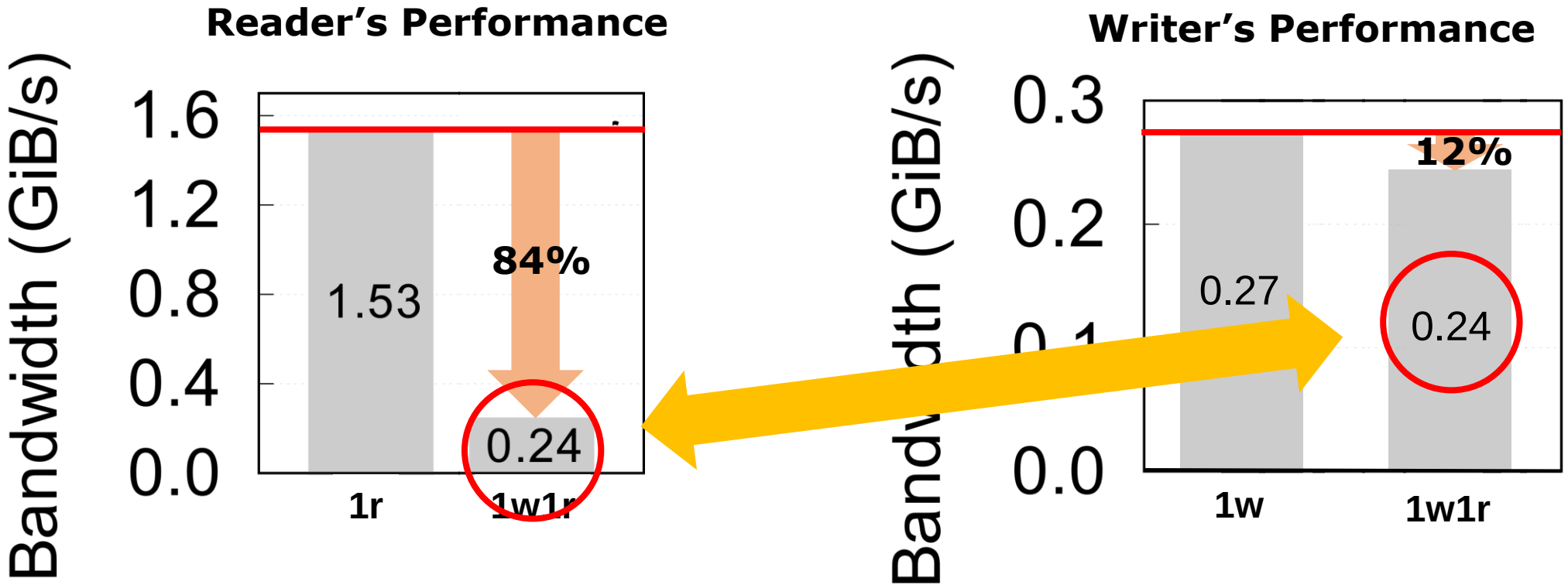
- Samsung 970 Pro 512 Gbyte, NVMe SSD.
- `fio` benchmark: "Direct & Sync" options
  - All the write requests are dispatched with the FUA flag.
- Workload Name: $\{N_W\}$w$\{N_R\}$r
  - N_W: The number of writers / N_R: The number of readers
  - ex) Single Reader (1r)
  - ex) Two readers & one writer (1w2r)

FUA Interference Analysis



- According to I/O type of concurrent worker, the bandwidth significantly varies.
- FUA-flagged write drops the reader's performance mostly.

Unfairness

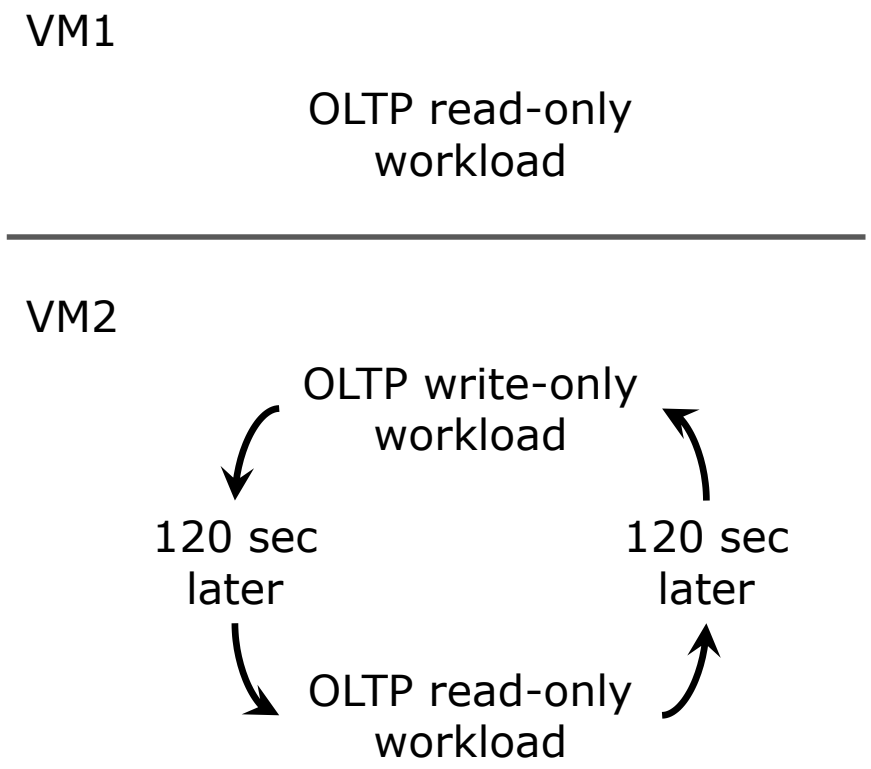


Unfairness between the read & FUA-flagged write.

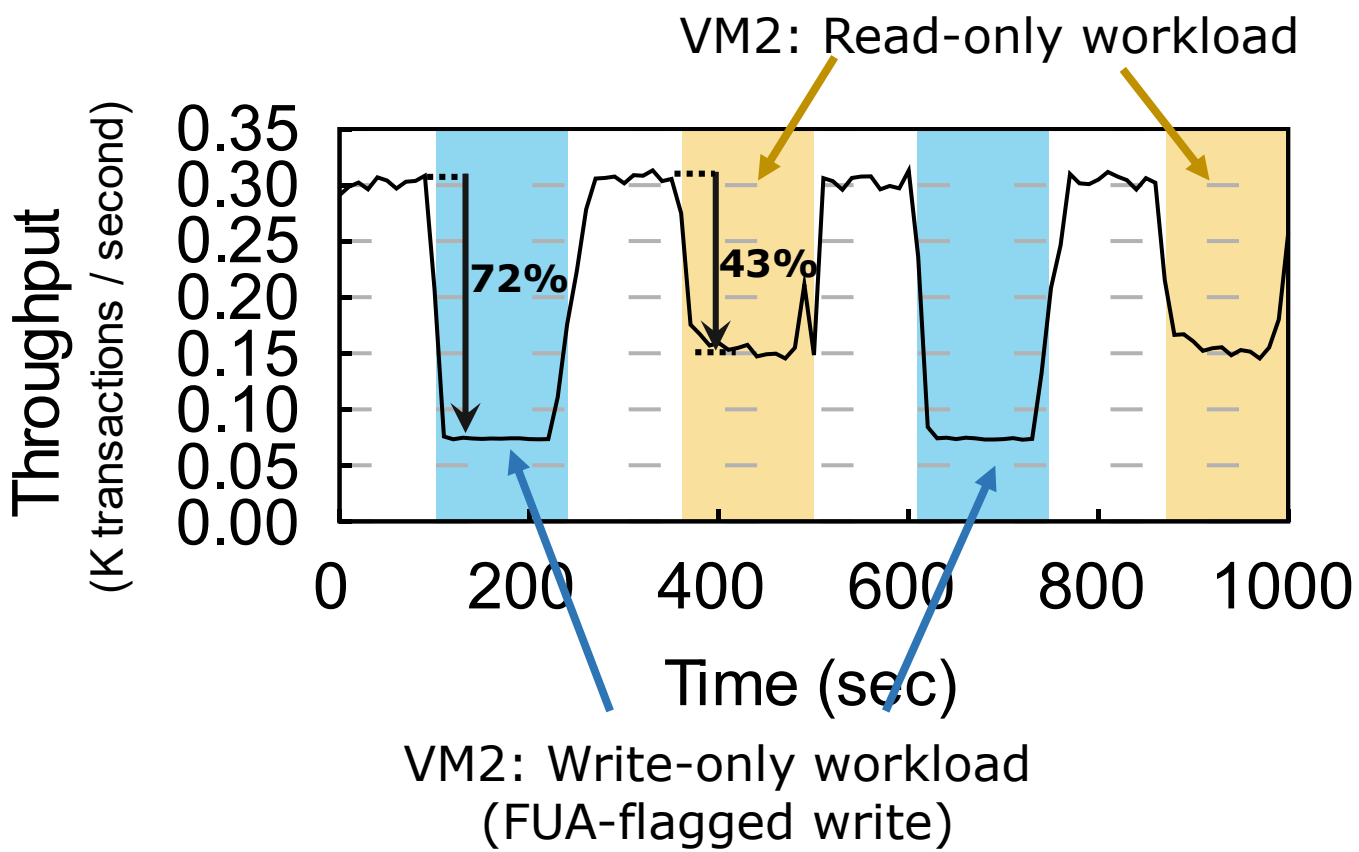
Real-World Workload

QEMU-KVM directsync cache mode

All the write requests are flagged with FUA.



VM1's Performance



Fair I/O Scheduling

- CFQ (Completely Fair Queueing)
- BFQ (Budget Fair Queueing)
- Deadline scheduler

→ *Provide fair I/O performance **among processes.***

☹ They do not consider the different I/O types.

- FIOS (FAST'12)

→ *Resolve **read/write interference** in host level.*

☹ It just blocks all write requests during dispatching the read requests.

- P/E Suspension (FAST'12)

→ *Resolve **read/write interference** in firmware level.*

☹ User cannot choose whether to adopt or not.

TABS per-Type fAir Bandwidth I/O Scheduler

Overview

- **Fairness Goal**
  - For each I/O type,

    (1) Bandwidth ∝ Maximum Bandwidth

    (2) Bandwidth ∝ Dispatch Rate

- **Key Idea**
  - Control dispatch rate of the FUA-flagged write to achieve the fair bandwidth.

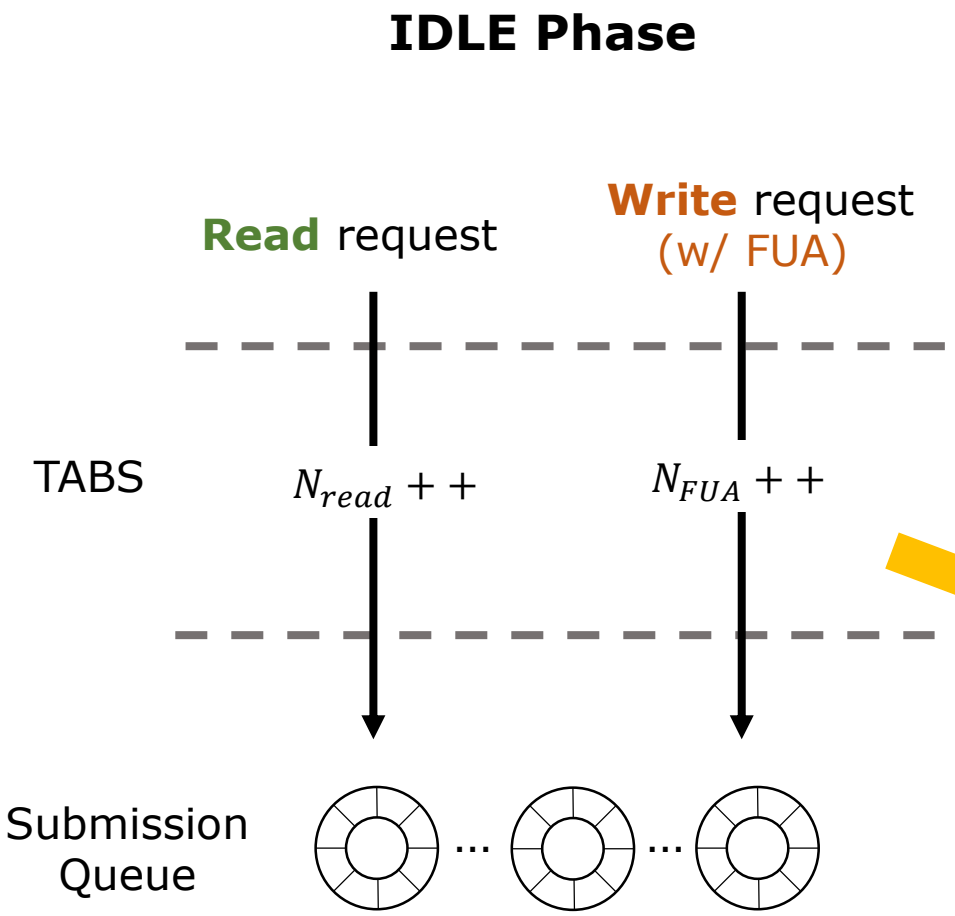
    (1) Two-phase Dynamic Scheduling

    ➔ To respond the various workloads.

    (2) Software-based Feedback

    ➔ For more precise scheduling according to the environment.

Two-phase Dynamic Scheduling



N: # of dispatched I/Os

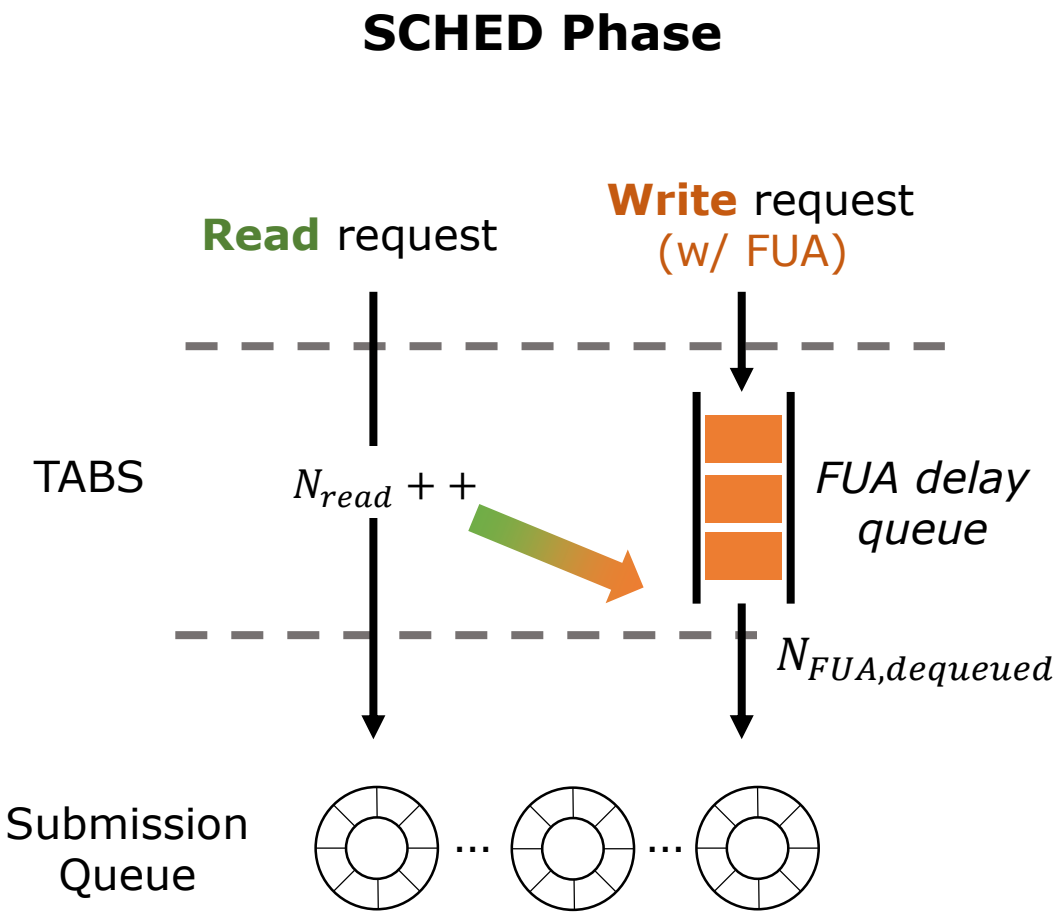
- IDLE Phase
  - TABS observes the I/O pattern of current workload.
  - Scheduling is disabled.
  - TABS counts the number of dispatched I/O requests for each I/O type (read & FUA write).
  - Phase is switched to SCHED when total I/O dispatch rate exceeds the threshold.

Fairness Goal: $Fair.BW$

$$Fair.BW_{read} = Max.BW_{read} \times \frac{N_{read}}{N_{read} + N_{FUA}}$$

$$Fair.BW_{FUA} = Max.BW_{FUA} \times \frac{N_{FUA}}{N_{read} + N_{FUA}}$$

Two-phase Dynamic Scheduling



- SCHED Phase
  - TABS inserts the FUA-flagged write requests into *FUA delay queue*.
  - TABS only dispatches the FUA writes as many as $N_{FUA,dequeued}$.
  - Throttling factor is the main factor that determines the I/O performance.

$$Throttling\ Factor = N_{read}\ /N_{FUA}$$

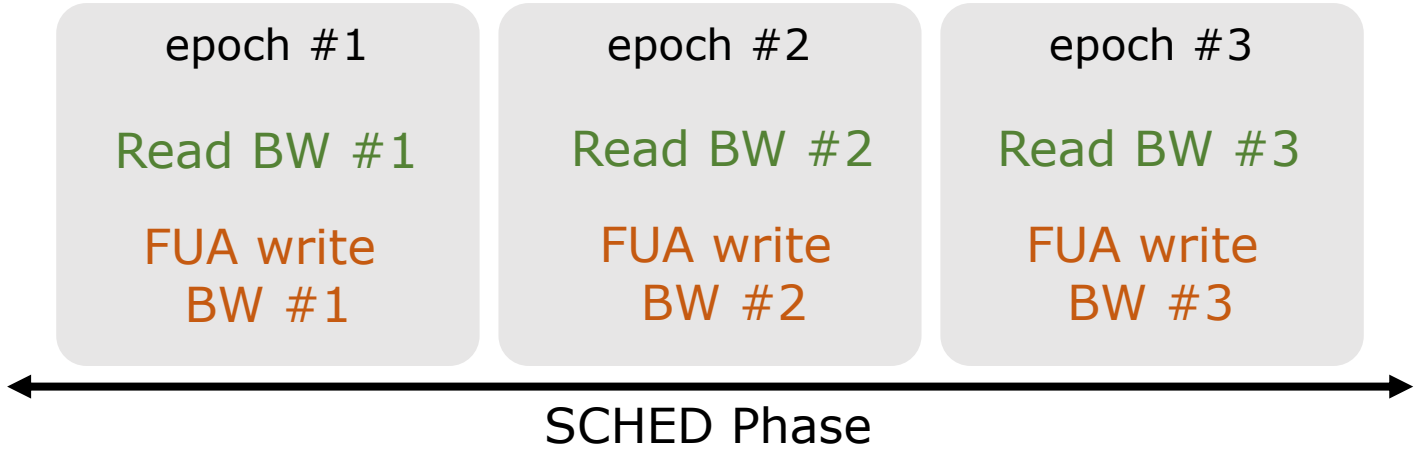
$$N_{FUA,dequeued} = Throttling\ Factor \times N_{read}$$

N: # of dispatched I/Os

Software-based Feedback

- TABS periodically adjusts the throttling factor to guarantee the fairness more precisely.

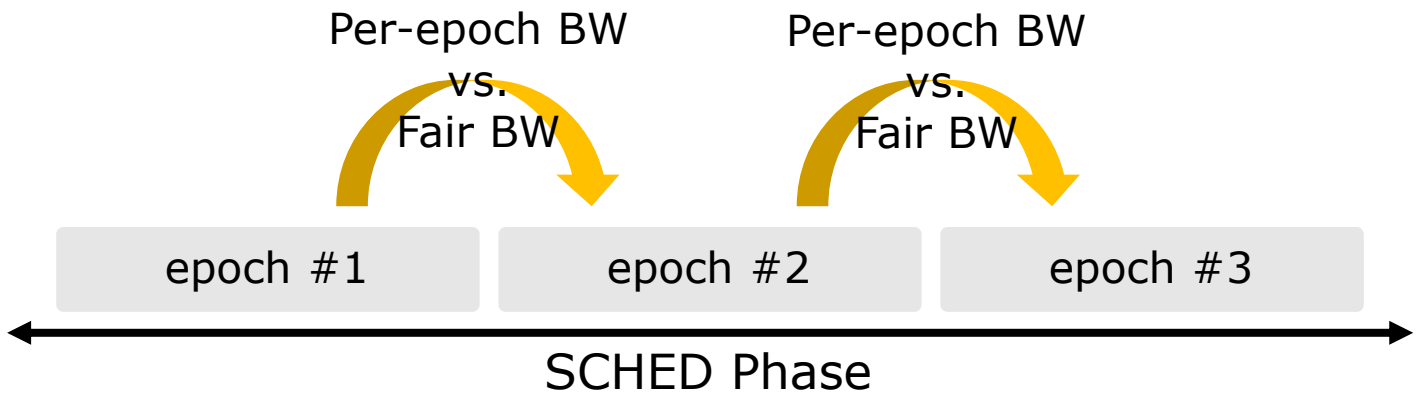
- TABS divides the SCHED phase into the same time interval, *"epoch"*.
- TABS keeps monitoring **the per-epoch bandwidth of each I/O type.**



Software-based Feedback

- For every end of the epoch, TABS performs the feedback.
  - For the each type of the I/O, compares **per-epoch bandwidth** and **fair bandwidth**.
  - Adjusts the throttling factor to minimize the gap between the two bandwidths.

For the BW of FUA-flagged write,	For the BW of read,
$Throttling\ Factor\ \uparrow$	$Throttling\ Factor\ \downarrow$



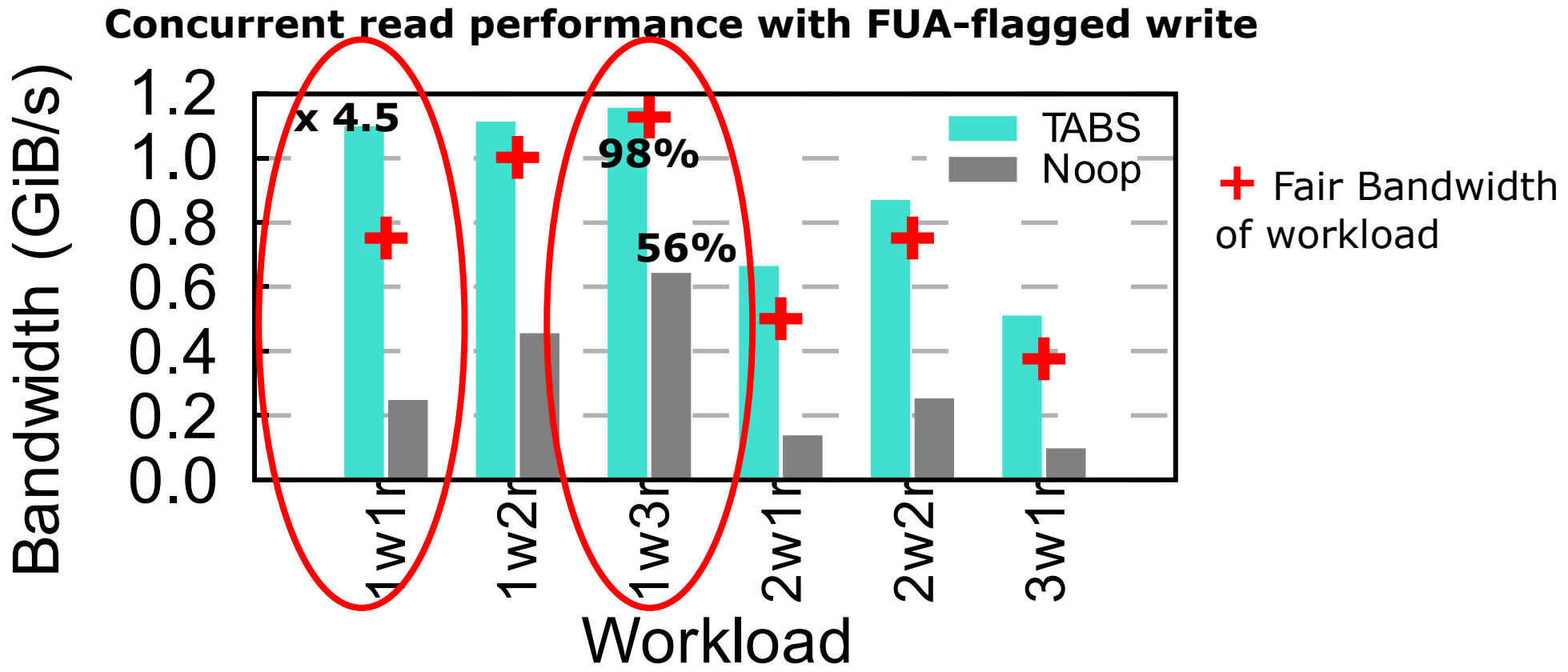
Evaluation

Environment

- Hardware Spec.
  - 4 Cores / 8 Threads (Intel(R) Core(TM) i7-4790 CPU @ 3.60GHz)
  - 16 Gbyte DRAM
  - Samsung 970 Pro (512 Gbyte) NVMe SSD

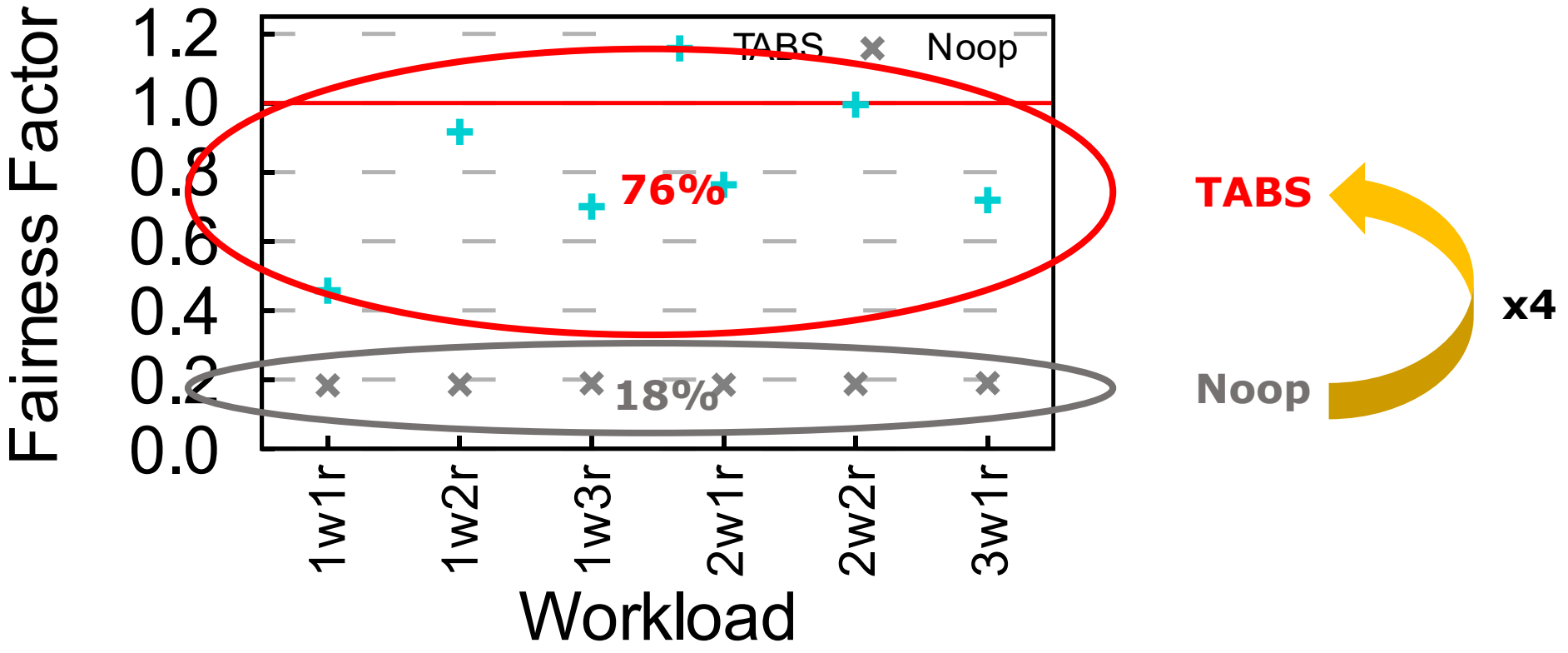
- Software Configurations
  - Centos 7.6 (Linux v5.8.5)
  - **`fio`** (version 3.7)
  - Compared with the **Noop** scheduler

Fairness Evaluation



- The read bandwidth is more closer to the fair bandwidth in TABS than Noop.
- TABS gives the device the possibility to accommodate more I/O traffic.

Fairness Factor



- Fairness factor represents how fair the read and FUA-flagged write are in terms of *bandwidth*.
- The fairness factor is close to 1 ➔ Read/FUA-flagged write requests become fairer.

Conclusion

Conclusion

- **FUA interference** is the cause of the unfairness between read and FUA-flagged write.

- TABS provides the fairness between **the different types of I/Os**.

  (1) Bandwidth ∝ Maximum Bandwidth

  (2) Bandwidth ∝ Dispatch Rate

- To achieve the fair bandwidth, TABS **throttles the FUA-flagged write requests**.

Two-phase Dynamic Scheduling

To respond the various workloads.

Software-based Feedback

For more precise scheduling according to the environment.

- TABS achieves **4 times higher fairness** than the Noop scheduler.

Thank you

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